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RESEARCH MEMORANDUM

LONGITUDINAL STABILITY AND CONTROL CHARACTERISTICS OF A SEMISPAN AIRPLANE MODEL AT TRANSONIC SPEEDS AS OBTAINED BY THE TRANSONIC-BUMP METHOD

By

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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LONGITUDINAL STABILITY AND CONTROL CHARACTERISTICS OF A SEMISPAN AIRPLANE MODEL AT TRANSONIC SPEEDS AS OBTAINED BY THE TRANSONIC-BUMP METHOD

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SUMMARY

An investigation has been made in the Langley high-speed 7- by 10-foot tunnel using the transonic-bump method to determine the longitudinal stability and control characteristics of a semispan airplane model at transonic speeds.

The results of the investigation indicated an increase in the maneuvering stability through the transonic range, but regions of instability were indicated by the slope of the curve of stabilizer incidence for trim against Mach number at all center-of-gravity positions tested. Trim could be maintained in level flight throughout the speed range, however, with about 1° change in stabilizer deflection regardless of the center-of-gravity location.

The variation of lift-curve slope and the angle of attack for zero lift with Mach number agreed closely with results obtained by the NACA wing-flow method, but a more linear variation with Mach number of the stabilizer incidence for trim was obtained by the transonic-bump method.

INTRODUCTION

Tests were made using the transonic-bump method to determine the longitudinal stability and control characteristics in the transonic range of a semispan airplane model similar to a proposed research vehicle. A comparison was made with results obtained for the same model by the NACA wing-flow method.

The model was mounted on a pivot and was free to trim at zero pitching moment. The lift coefficient and angle of attack for trim at various stabilizer settings were obtained for four center-of-gravity positions. The tests were made through a Mach number range from 0.60 to 1.20.

COEFFICIENTS AND SYMBOLS

C_L trim lift coefficient (L/qS)

C_{L_A} airplane lift coefficient (W/qS)

L trim lift, pounds

q effective dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$

S wing area, square feet

ρ air density, slugs per cubic foot

V air velocity, feet per second

α trim angle of attack, degrees

M Mach number

c' wing mean aerodynamic chord, M.A.C., feet

i_t stabilizer incidence with respect to fuselage center line, degrees (positive when leading edge moves up)

W airplane weight, pounds

R Reynolds number

h altitude, feet

n_m maneuver point, percent M.A.C.

c.g. center of gravity, percent M.A.C.

g acceleration of gravity, feet per second

C_{L_α} rate of change of trim lift coefficient with trim angle of attack

MODEL AND APPARATUS

A drawing of the semispan airplane model is given in figure 1 and the geometric characteristics are given in table I. The model was obtained from the Langley Flight Research Division and had been used in a previous investigation by the NACA wing-flow method (reference 1).

The model was mounted on a free-float mount so that it was free to trim at all speeds and was designed so that the horizontal-tail setting could be varied. It was possible to obtain data at various simulated airplane center-of-gravity positions by moving the model pivot point fore and aft.

The tests were made in the Langley high-speed 7- by 10-foot tunnel by the transonic-bump method which involves placing a small semispan model in the high-velocity flow field generated over a curved surface. This method of testing is fully described in reference 2.

The trim angle of attack was measured with a calibrated slide wire rheostat and the trim lift was measured with a calibrated electrical strain gage. Both measurements were observed visually on a galvanometer.

TESTS

The Mach number distribution over the bump (see reference 2) indicates that the Mach number at the wing is slightly higher than that at the tail at the highest Mach numbers. It is possible that this difference might result in the masking or exaggeration of trim or stability changes.

The variation of Reynolds number with Mach number for these tests is shown in figure 2.

No tares were applied to the data to account for the presence of an end plate and, because of the small size of the model with respect to the tunnel, jet-boundary corrections were neglected.

Tests were made through a Mach number range from 0.60 to 1.20 with various stabilizer settings at center-of-gravity positions of -0.8, 14.5, 25.0, and 39.4 percent mean aerodynamic chord. The stabilizer settings covered a range from -2.4° to 4.0°.

RESULTS AND DISCUSSION

The variation of trim angle of attack and lift coefficient with Mach number is presented for several stabilizer incidences and center-of-gravity locations in figure 3. Below about $M = 0.80$ the model did not experience any sudden trim changes. In the range $0.80 < M < 1.00$ there were rather irregular changes in trim dependent upon the stabilizer incidence and the center-of-gravity location. Above $M \approx 1.00$ conditions free from sudden trim changes again prevailed.

The variation of the maneuver point with Mach number of an airplane geometrically similar to the model $\left(\frac{W}{S} = 50 \text{ lb/sq ft}, h = 30{,}000 \text{ ft}\right)$ was determined as follows:

For a given Mach number the variation of i_t with C_L and α was obtained for all center-of-gravity positions. The slopes $\frac{di_t}{dC_L}$ and $\frac{di_t}{d\alpha}$ were measured at the lift coefficient for level flight at the specific Mach number (figs. 4 and 5). The variation of $\frac{di_t}{dC_L}$ and $\frac{di_t}{d\alpha}$ with center-of-gravity position determined a point at which $\frac{di_t}{dC_L}$ and $\frac{di_t}{d\alpha}$ were zero. This position corresponded to the maneuver point[1] or the point at which no change in stabilizer incidence is required to change the lift coefficient and angle of attack.

The variation of the maneuver point with Mach number (fig. 6) indicated a rapid increase in maneuvering stability through the transonic range. The change in stabilizer incidence required for a 2g turn at various Mach numbers for each center-of-gravity position is presented in figure 7. It is evident that moderate changes in center-of-gravity position would have little effect on the maneuverability of an airplane similar to this model in the high subsonic and low supersonic range.

The data of figure 3 were used in conjunction with figure 4 to obtain the stabilizer incidence required for trim through the Mach number range for various airplane center-of-gravity locations. (See fig. 8.) It is seen that at any center-of-gravity position scarcely more than 1° stabilizer change is required to trim the airplane in the Mach number range from 0.6 to 1.1. It is also seen that an unstable region occurred for all center-of-gravity positions (that is, an increase in speed or a decrease in lift coefficient must be trimmed by a negative control movement) in the transonic range. At a given Mach number this instability is more a function of such factors as the rates of change of maneuvering margin, stabilizer effectiveness, and zero-lift pitching-moment coefficient with Mach number than the actual maneuvering margin at the specific Mach number.

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[1]This procedure neglects the i_t required to overcome the pitching moment induced by curvature of the flight path. However, this incurred an error of less than 1 percent in n_m because of the high airplane relative density factor.

CORRELATION WITH WING-FLOW RESULTS

Trim lift curves for various Mach numbers are presented in figure 9. So that a greater number of points might be obtained to define the lift curves, values of C_L and α for all center-of-gravity positions were used and corrected to values trimmed at the 25-percent center of gravity by the following relation:

$$\Delta C_L = -(\Delta x)\left(\frac{c'}{l_t}\right)C_L$$

where

Δx distance between given center of gravity and 0.25c' center of gravity, percent M.A.C. (negative when given center of gravity is ahead of 0.25c')

l_t tail length measured from center of gravity to one-fourth of tail M.A.C., feet

This correction is approximate and assumes the total lift equal to the wing lift.

The variation of lift-curve slope and the angle of zero lift with Mach number is presented in figure 10. Fairly close agreement was obtained with the values determined from wing-flow tests, particularly below $M = 0.95$. A good correlation of C_{L_α} up to the force break is shown with values determined from a similar model tested at larger scale. The latter data (obtained at low speeds) were corrected for a slight difference in aspect ratio and include first-order effects of compressibility.

The variation of C_L and α with i_t obtained from figure 3 is presented in figures 11 and 12 with a comparison of the results obtained by the wing-flow method. Fairly good agreement was obtained at all Mach numbers except at 0.90 where the wing-flow method indicated considerably less C_L and α change with change in i_t. A comparison of the variation with Mach number of the i_t for trim $\left(\frac{W}{S} = 50 \text{ lb/sq ft}, h = 30{,}000 \text{ ft}\right)$ is presented in figure 13. There was generally fair agreement shown between the curves obtained by the two modes of testing. However, at $M \approx 0.90$ the wing-flow method indicated a sudden change in the i_t required for trim that was not as marked in the transonic-bump data.

CONCLUDING REMARKS

The results of tests made by the transonic-bump method of a semispan airplane model indicated an increase in the maneuvering stability (speed invariant) as characterized by a rearward shift of the maneuver point through the transonic range. For each center-of-gravity position tested, instability was indicated by the slope of the curve of stabilizer incidence for trim against Mach number between Mach numbers of 0.70 and 1.00. However, trim could be maintained throughout the Mach number range with a change in stabilizer deflection of only about 1°.

The variation of lift-curve slope and the angle of attack for zero lift with Mach number agreed closely with results obtained by the wing-flow method.

The variation with Mach number of the stabilizer incidence required for trim also agreed fairly well with results from the wing-flow tests at all Mach numbers except at 0.90 where a loss of stabilizer effectiveness (rate of change of trim lift with stabilizer deflection) was indicated by the wing-flow tests.

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REFERENCES

1. Zalovcik, John A., and Sawyer, Richard H.: Longitudinal Stability and Control Characteristics of a Semispan Airplane Model at Transonic Speeds from Tests by the NACA Wing-Flow Method. NACA ACR No. L6E15, 1946.

2. Schneiter, Leslie E., and Ziff, Howard L.: Preliminary Investigation of Spoiler Lateral Control on a 42° Sweptback Wing at Transonic Speeds. NACA RM No. L7F19, 1947.

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TABLE I

GEOMETRIC CHARACTERISTICS OF SEMISPAN MODEL

Wing:	
Area (semispan), sq in.	6.00
Semispan, in.	4.00
Mean aerodynamic chord, in.	1.56
Section	NACA $65_{(112)}$ - 110
Incidence, root	$2^{\circ}30'$
Incidence, tip	$2^{\circ}0'$
Chord, root, in.	2.00
Chord, tip, in.	1.00
Taper ratio	2:1
Aspect ratio	5.33
Dihedral, deg	0
Tail:	
Area (semispan), sq in.	1.56
Semispan, in.	1.66
Mean aerodynamic chord, in.	0.97
Section	NACA $65_{(112)}$ - 008
Chord, root, in.	1.25
Chord, tip, in.	0.62
Taper ratio	2:1
Aspect ratio	3.5
Dihedral, deg	0
Fuselage:	
Length, in.	7.97
Maximum diameter, in.	1.20

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[redacted]

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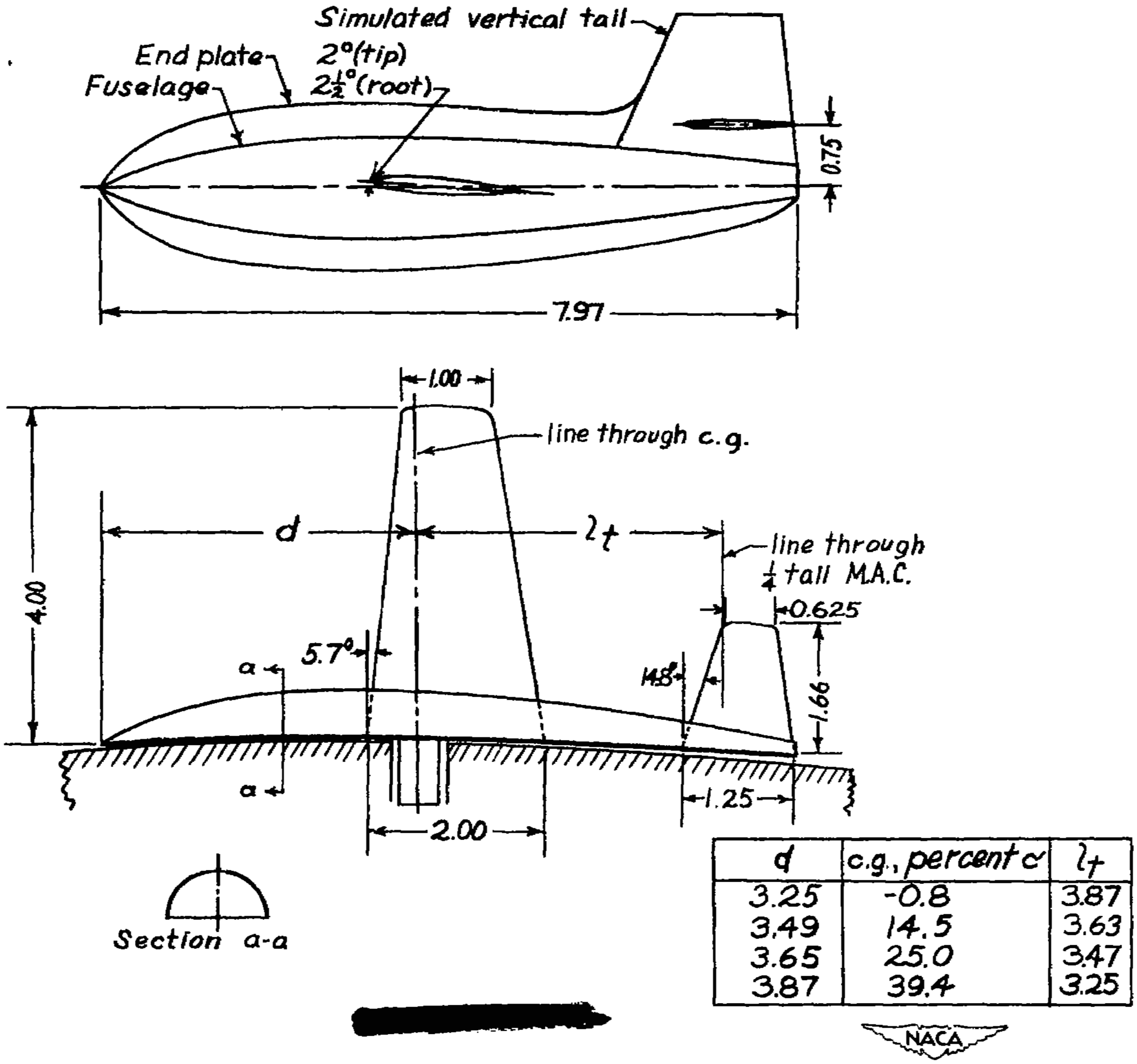


d	c.g., percent $\bar{c}$	l_t
3.25	-0.8	3.87
3.49	14.5	3.63
3.65	25.0	3.47
3.87	39.4	3.25

[redacted]

Figure 1.- Details of semispan airplane model. Dimensions in inches except where noted.

[redacted]

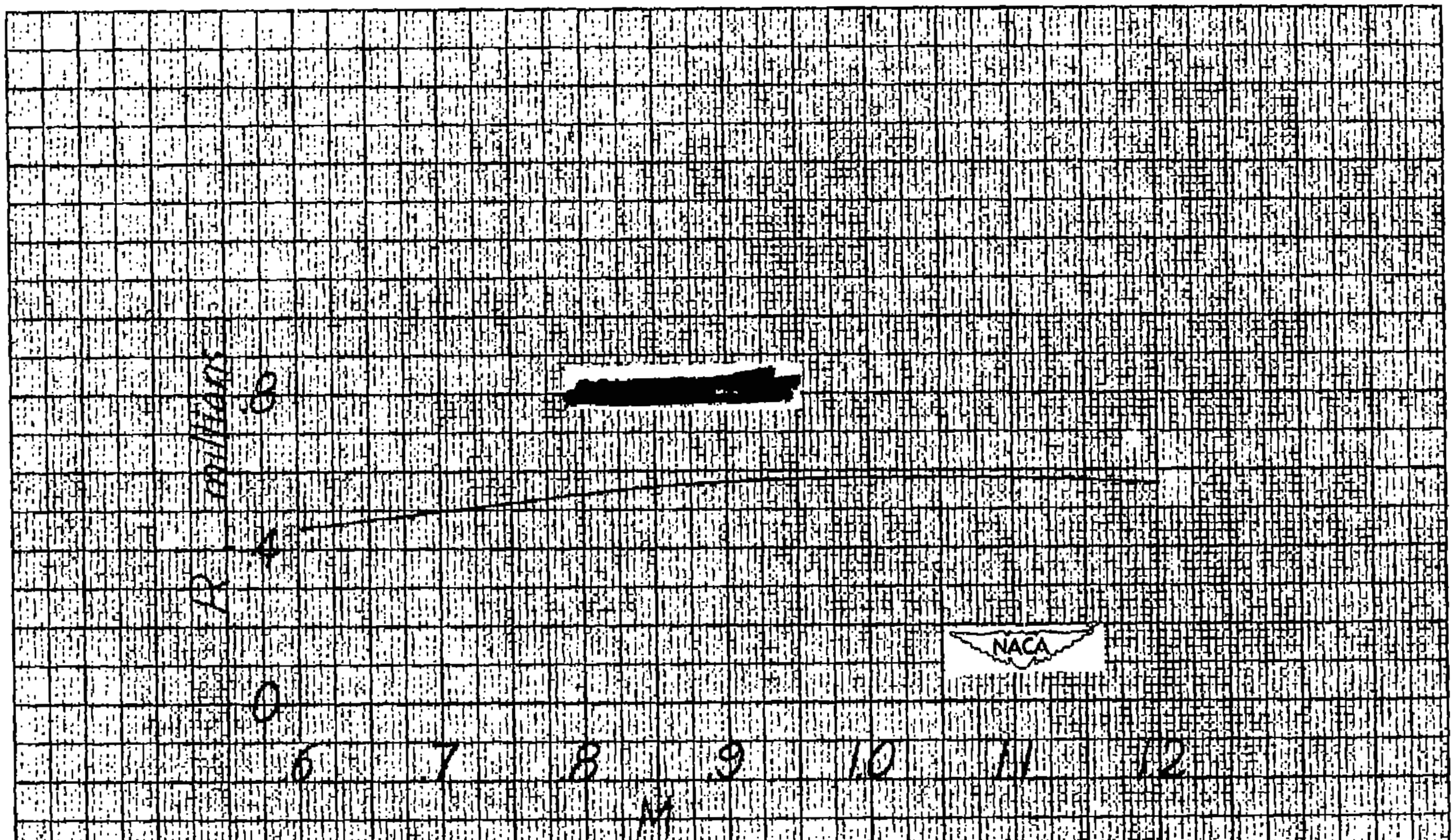
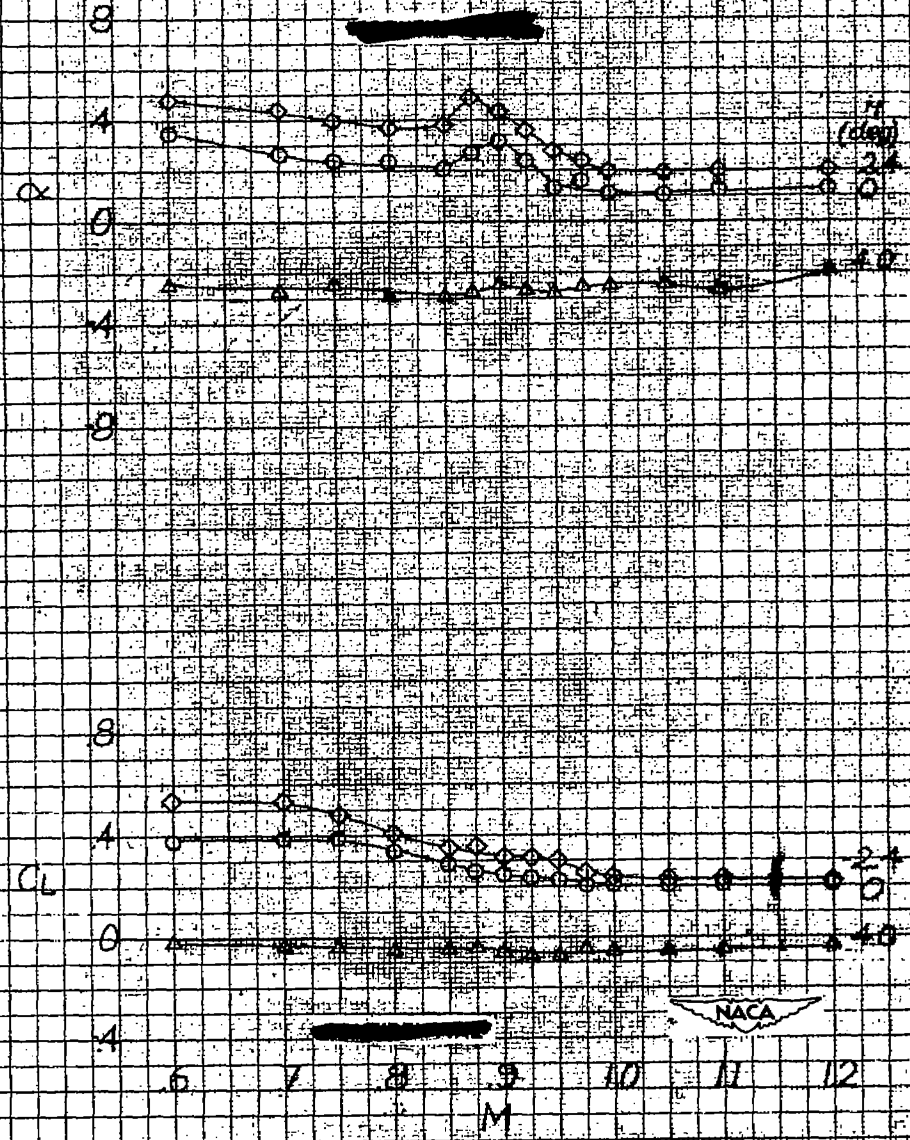


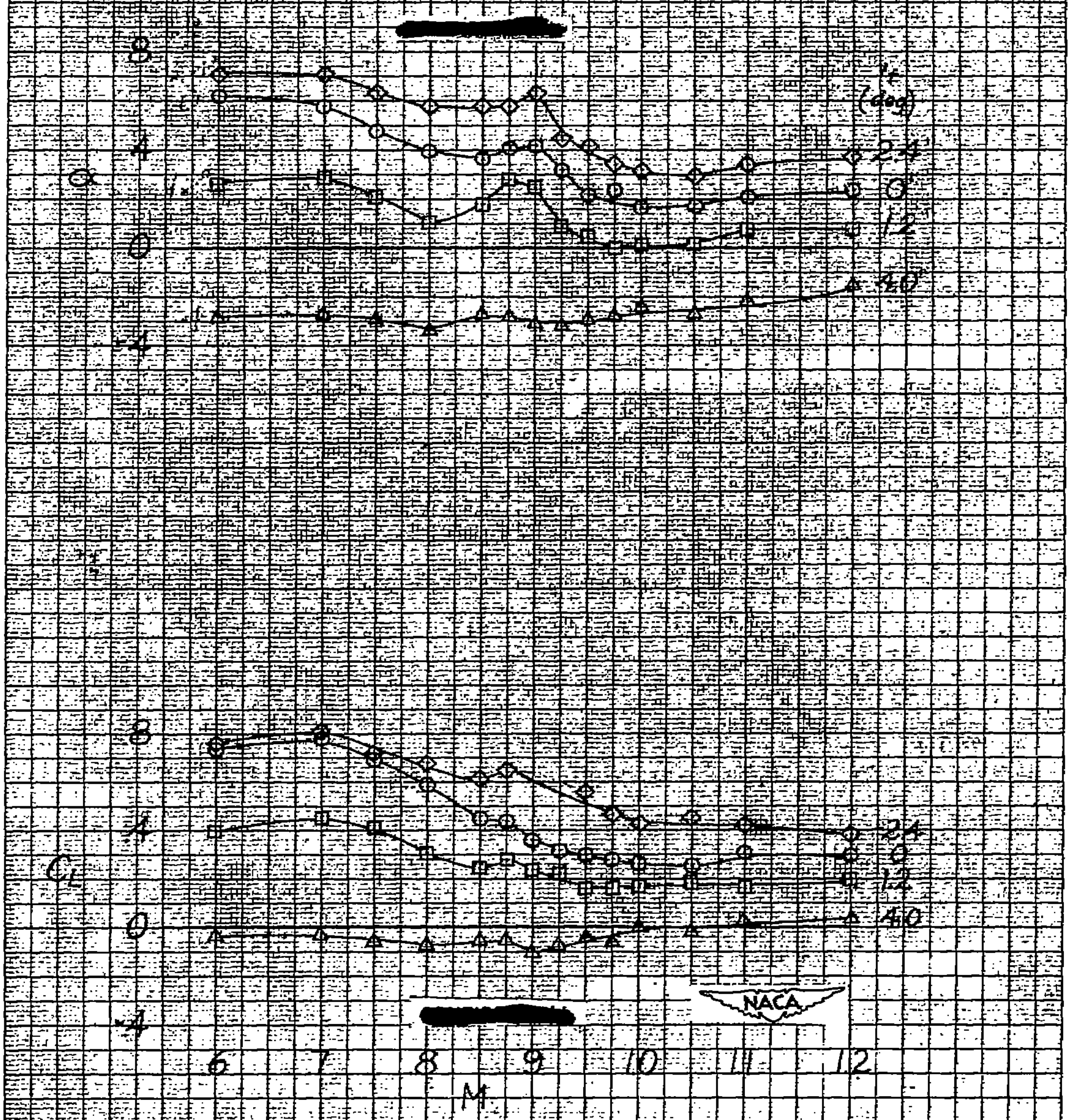
Figure 2.- Variation of Reynolds number with test Mach number.

[redacted]



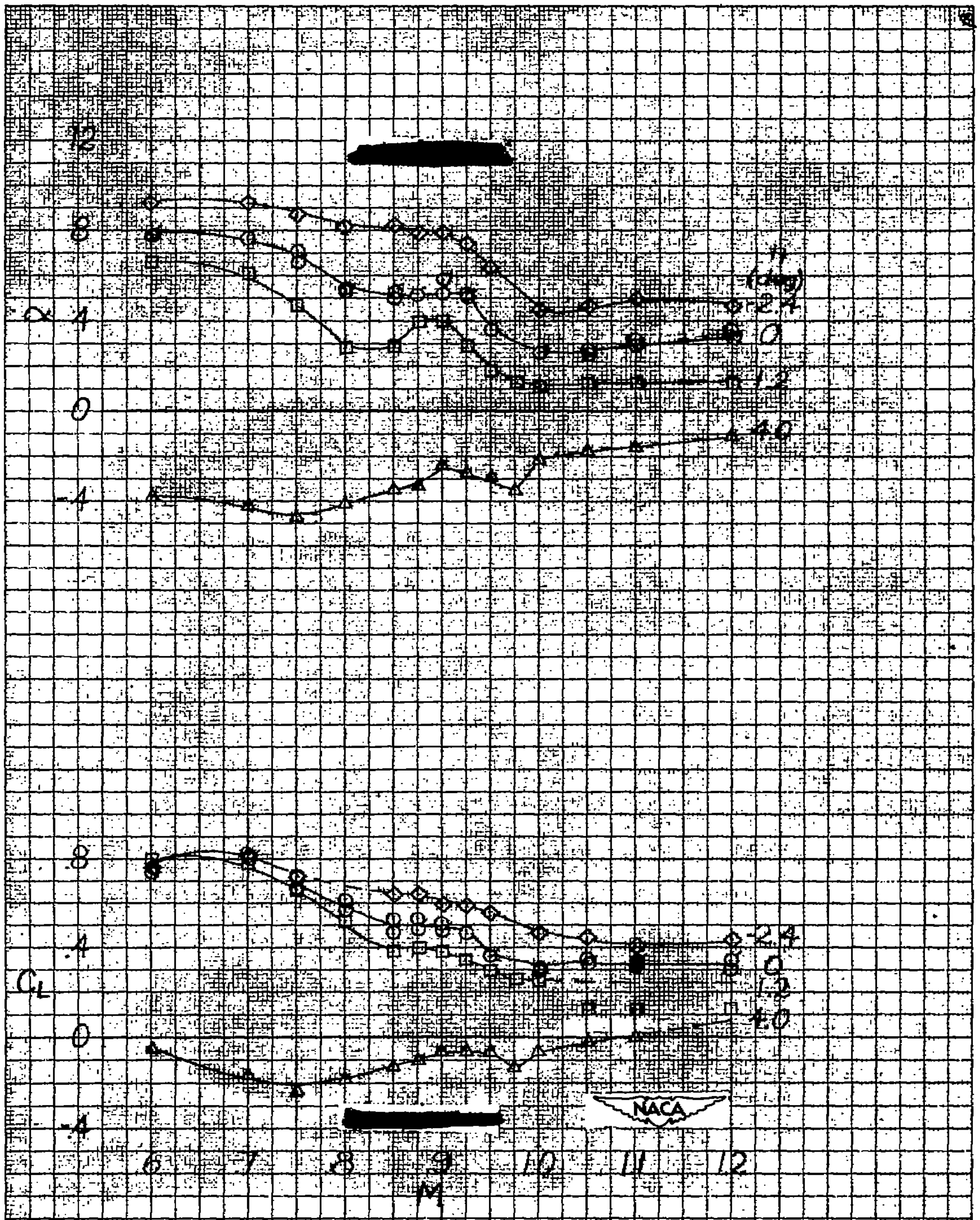
(a) C.g - 0.008c

Figure 3.- Variation of lift coefficient and angle of attack for trim with Mach number.



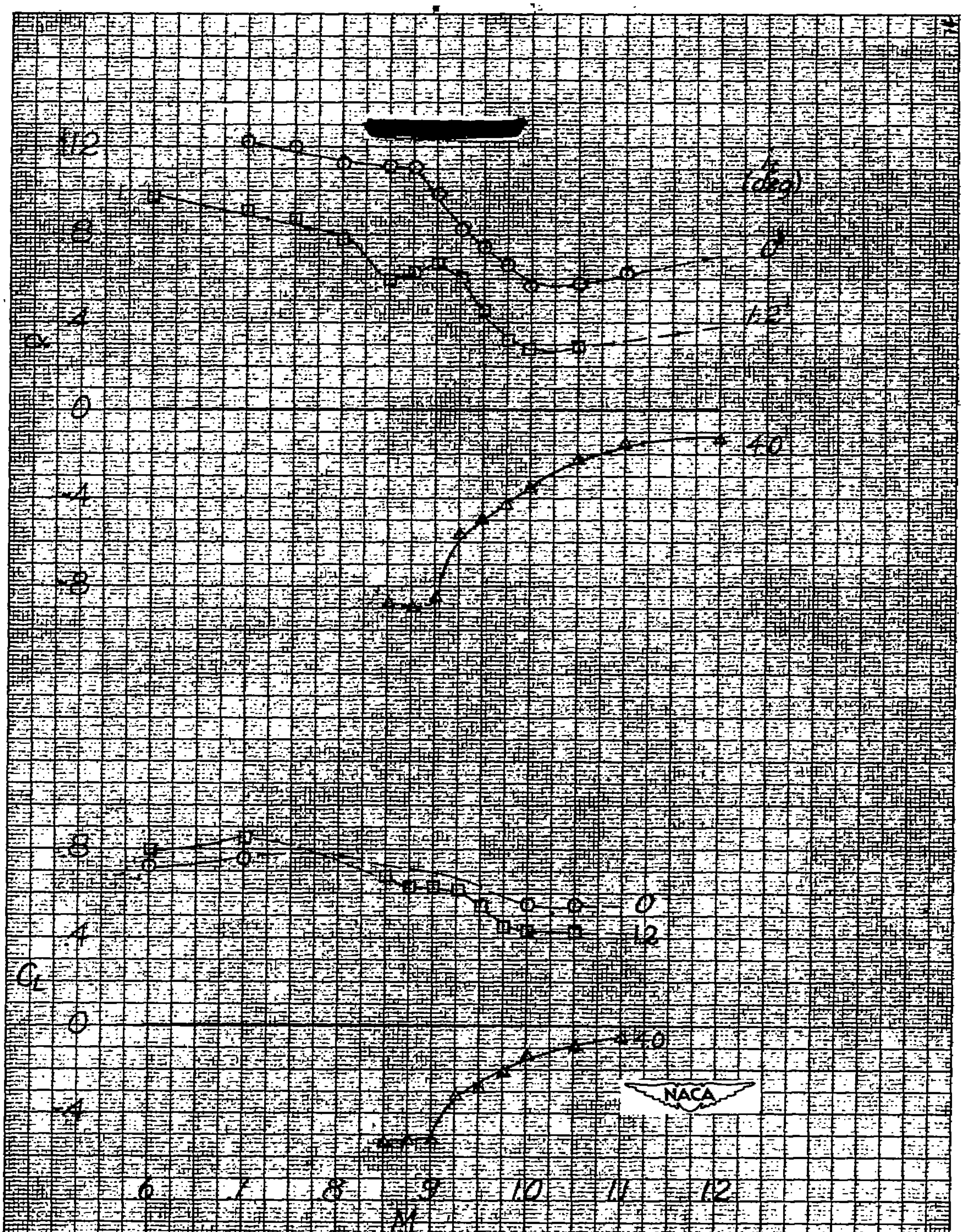
(b) C.g.-0.145c.

Figure 3- Continued



(c) c.g. = 0.25c'

Figure 3.- Continued.



(d) C.g. - 0.394c.

Figure 3- Concluded.

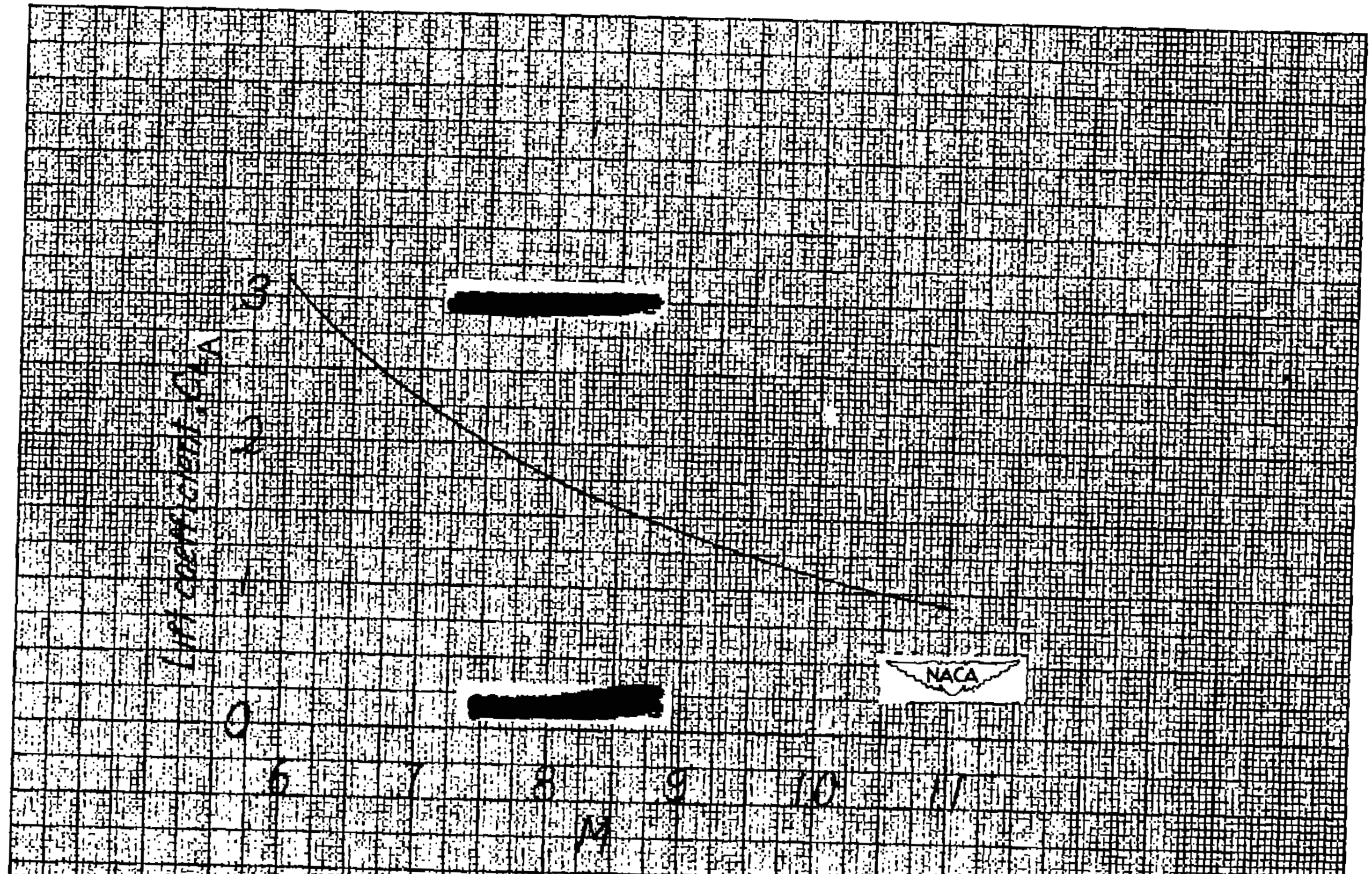


Figure 4.- Variation with Mach number of the lift coefficient for level flight. W/S=50 lb/sq ft; h=30,000 ft

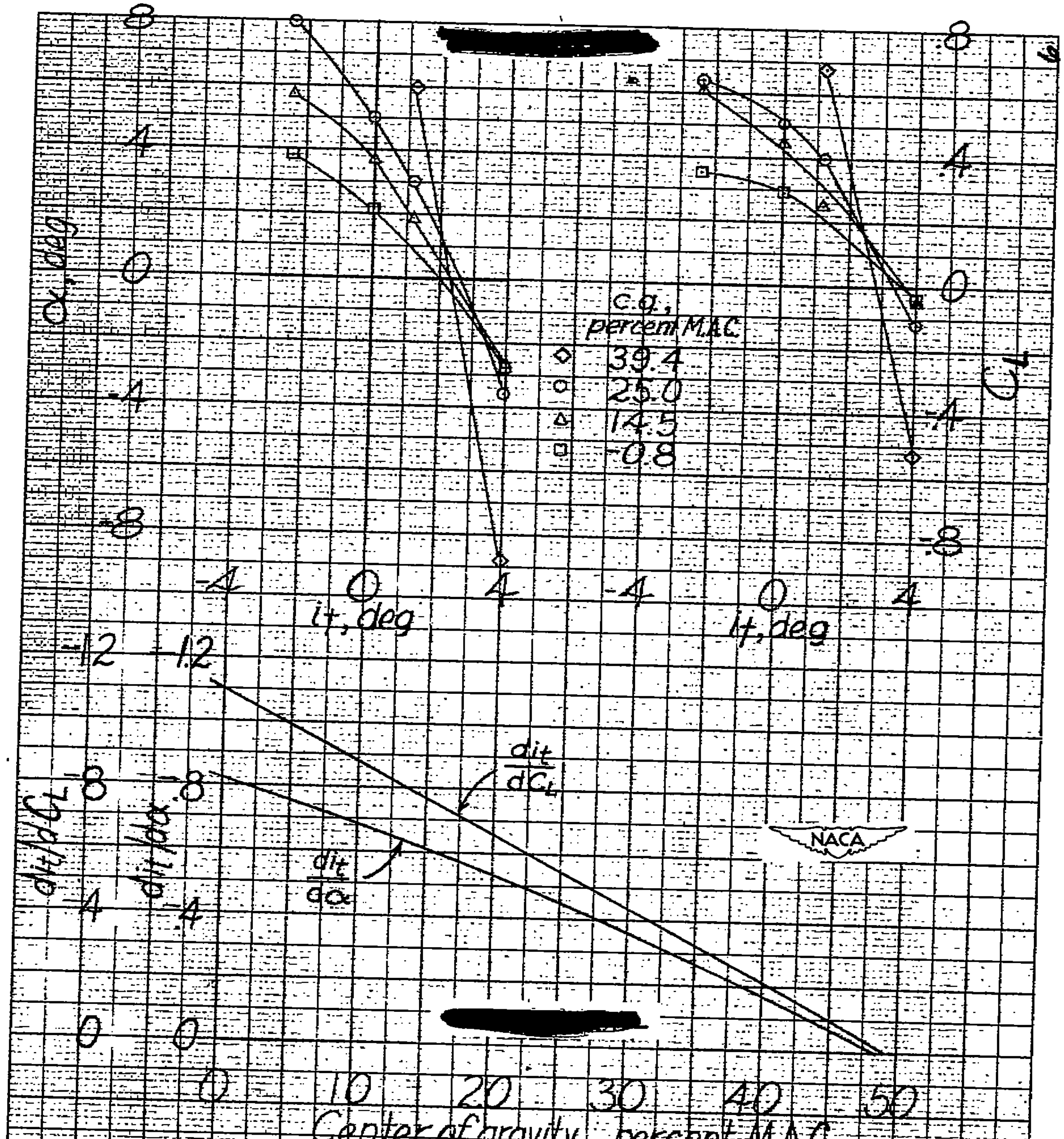


Figure 5.- Method of determining the maneuver point for M=0.85 W/S=50 lb/sq ft, h=30,000 ft.

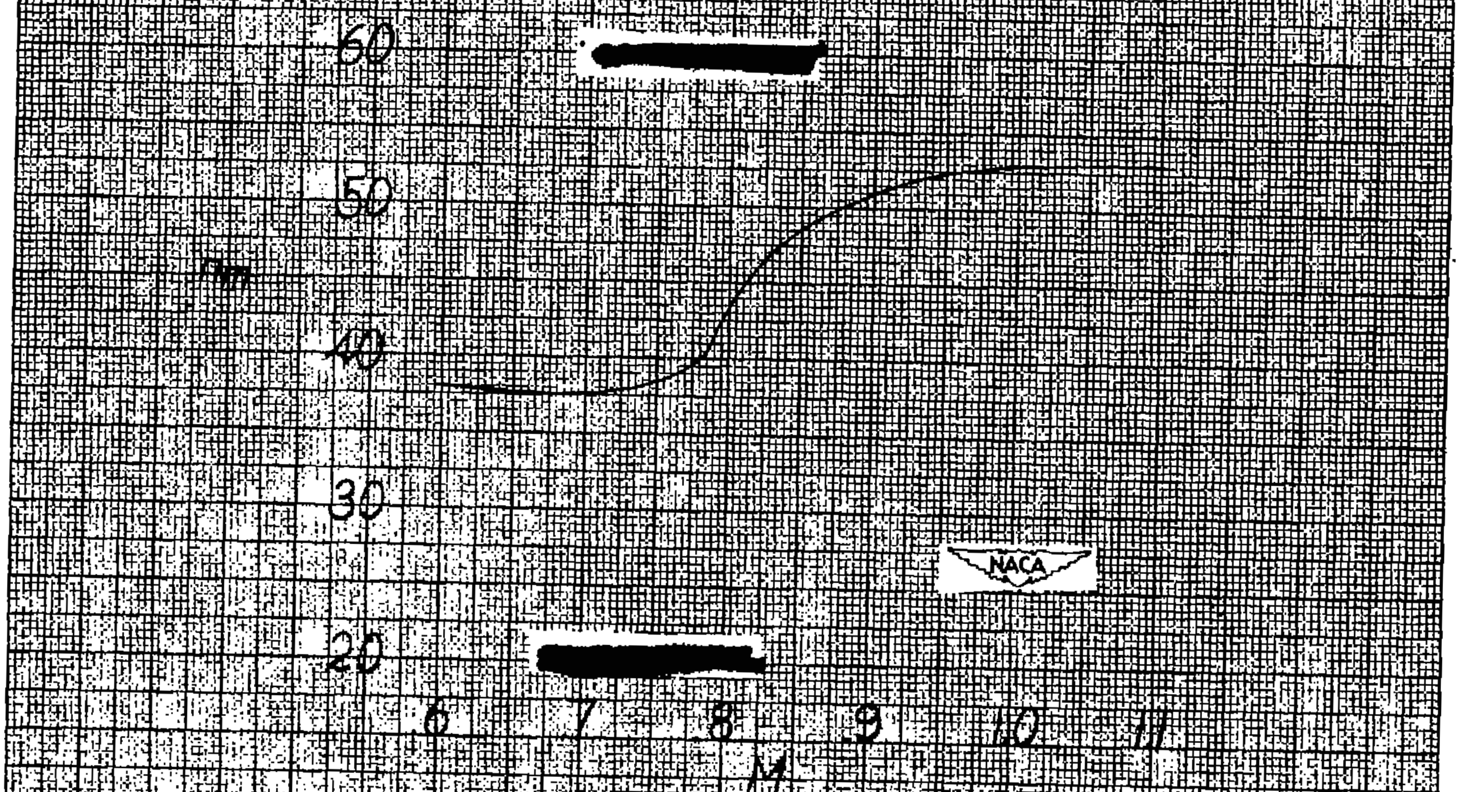


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Figure 6. Variation of maneuver point with Mach number. W/S=50 lb/sq ft, h=30,000 ft

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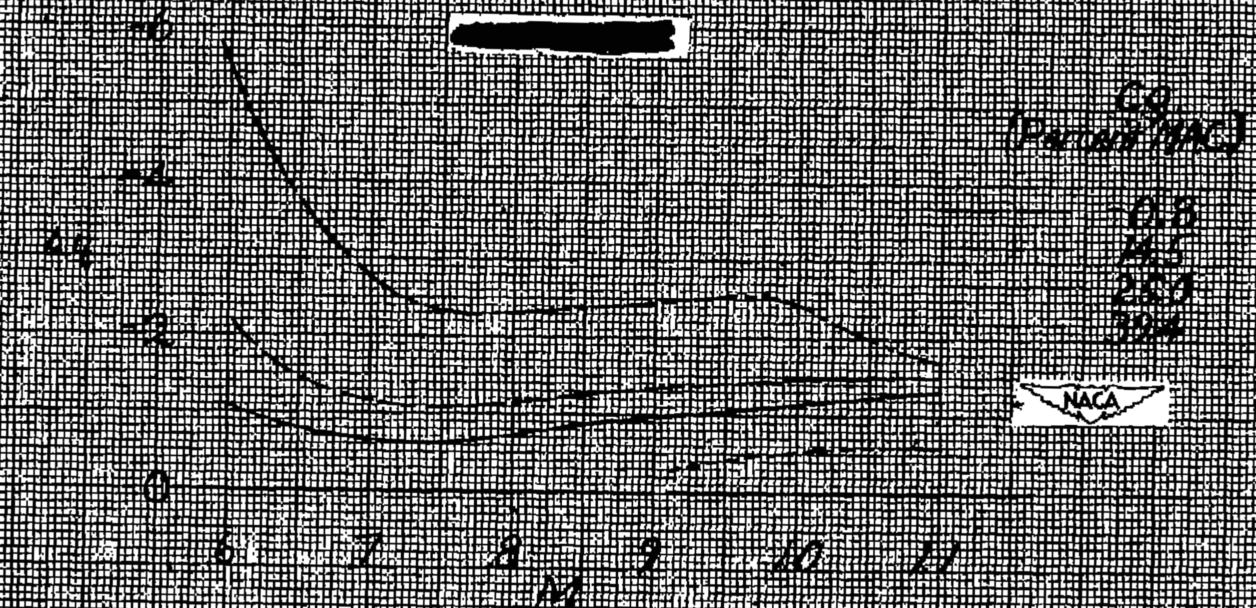

Figure 7.- Change in stabilizer deflection required for a 2g turn.

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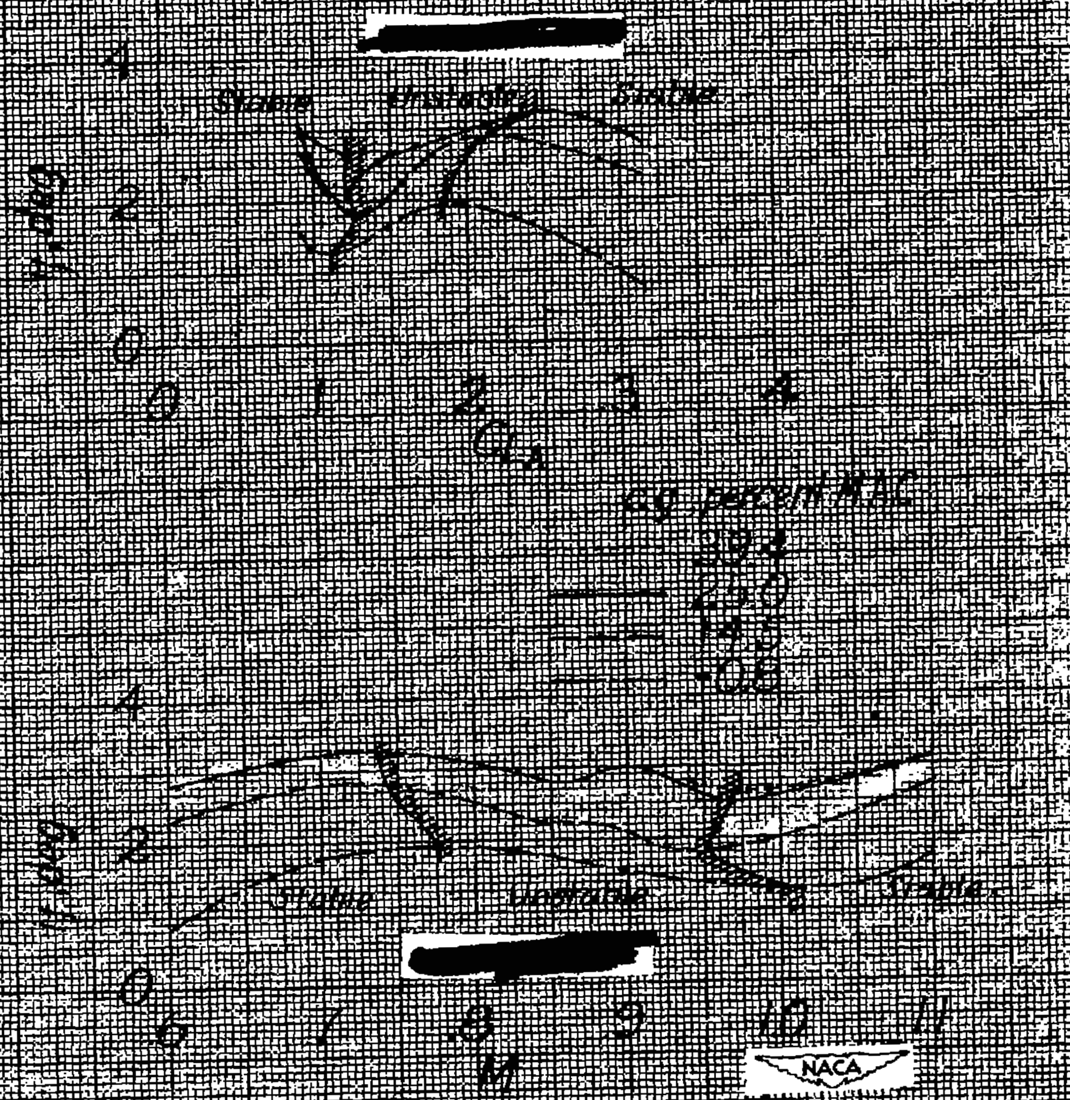

Figure 8.- Variation with lift coefficient and Mach number of the stabilizer incidence required for trim. W/S=50lb/sq ft, h=30,000 ft.

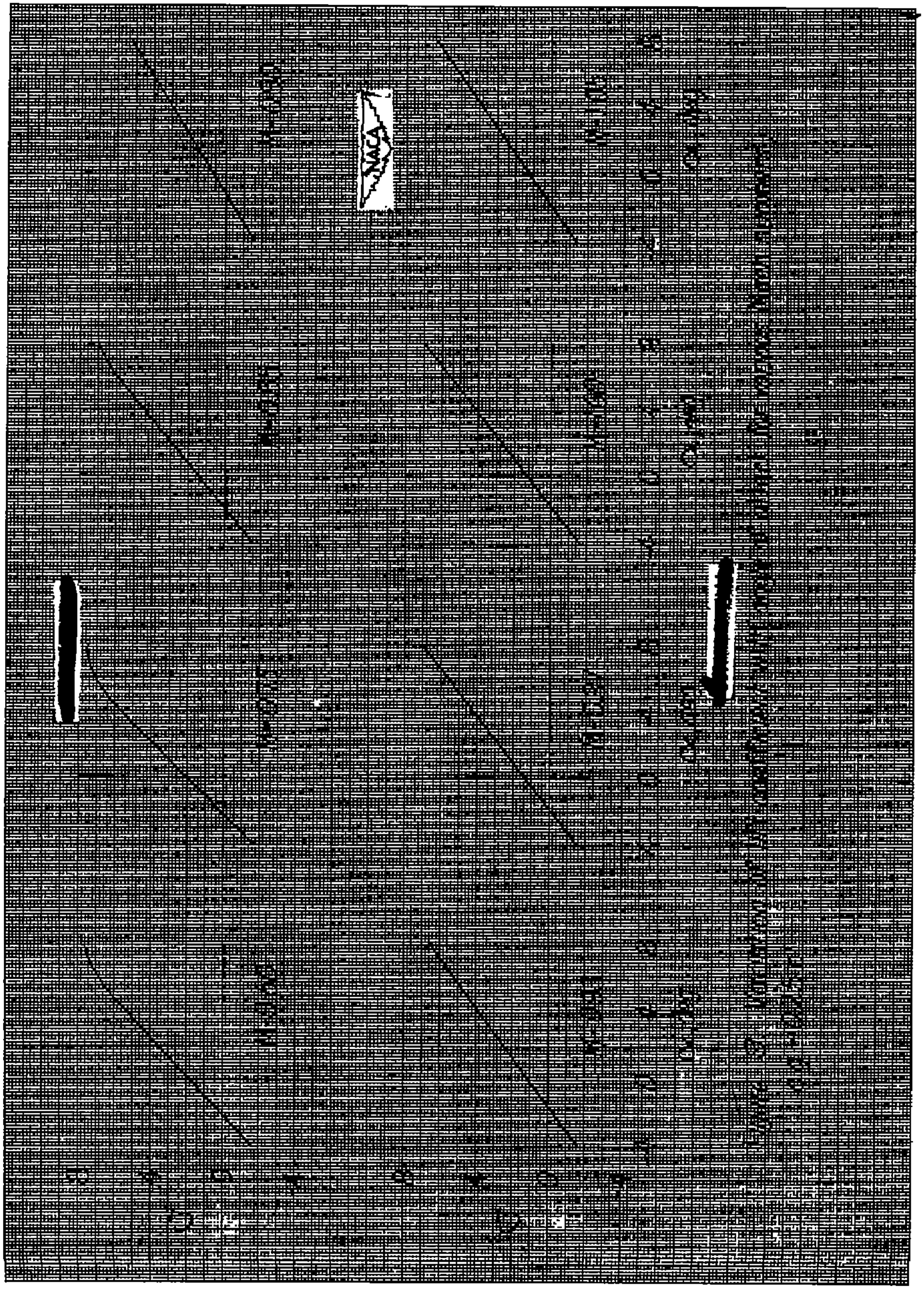

Figure 3.- Variation of lift coefficient with angle of attack for various Mach numbers.

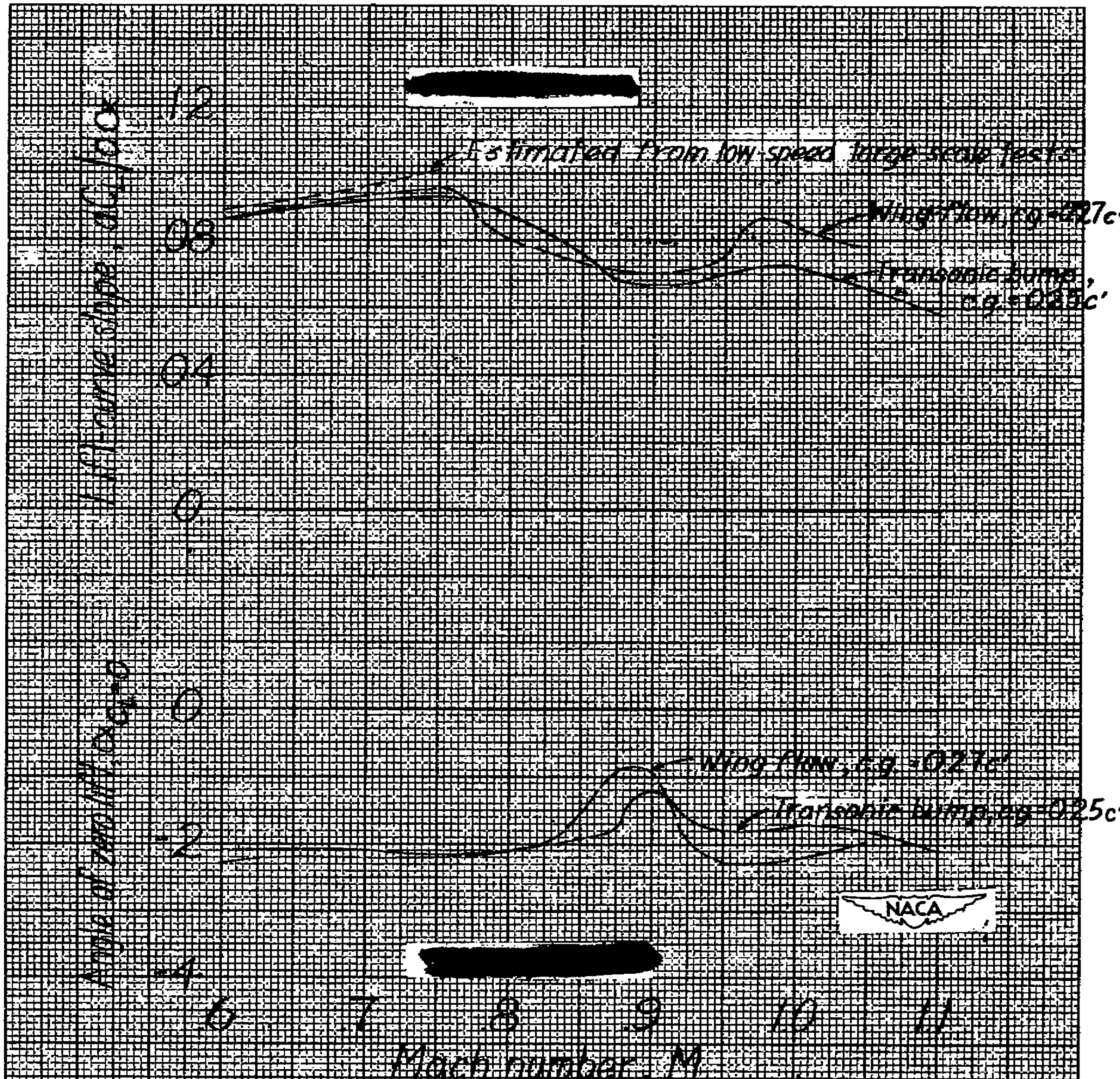

Figure 10- Variation of lift-curve slope and angle of zero lift with Mach number.

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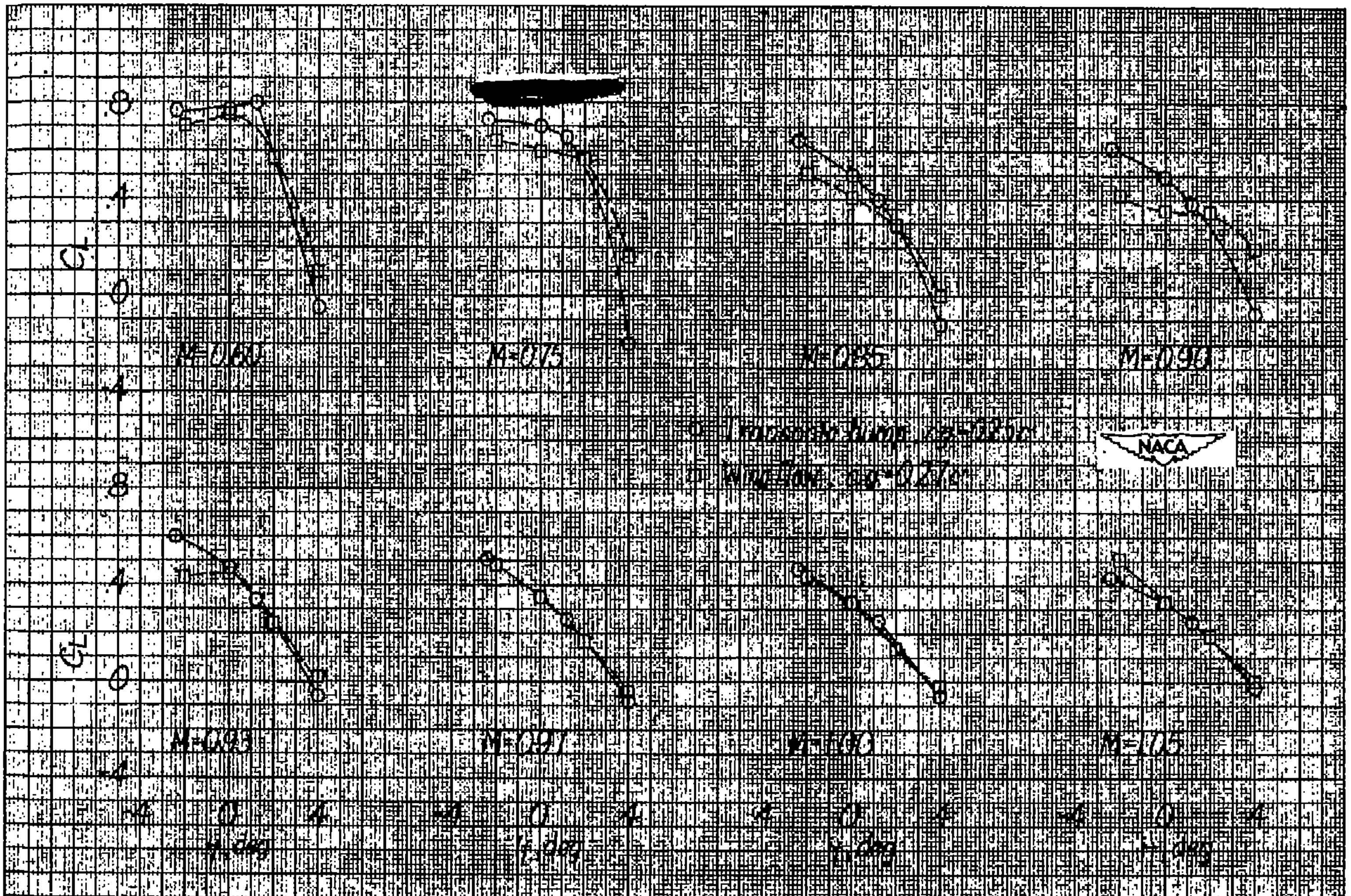

Figure 11.- Variation of lift coefficient for trim with stabilizer incidence for various Mach numbers.

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[redacted]

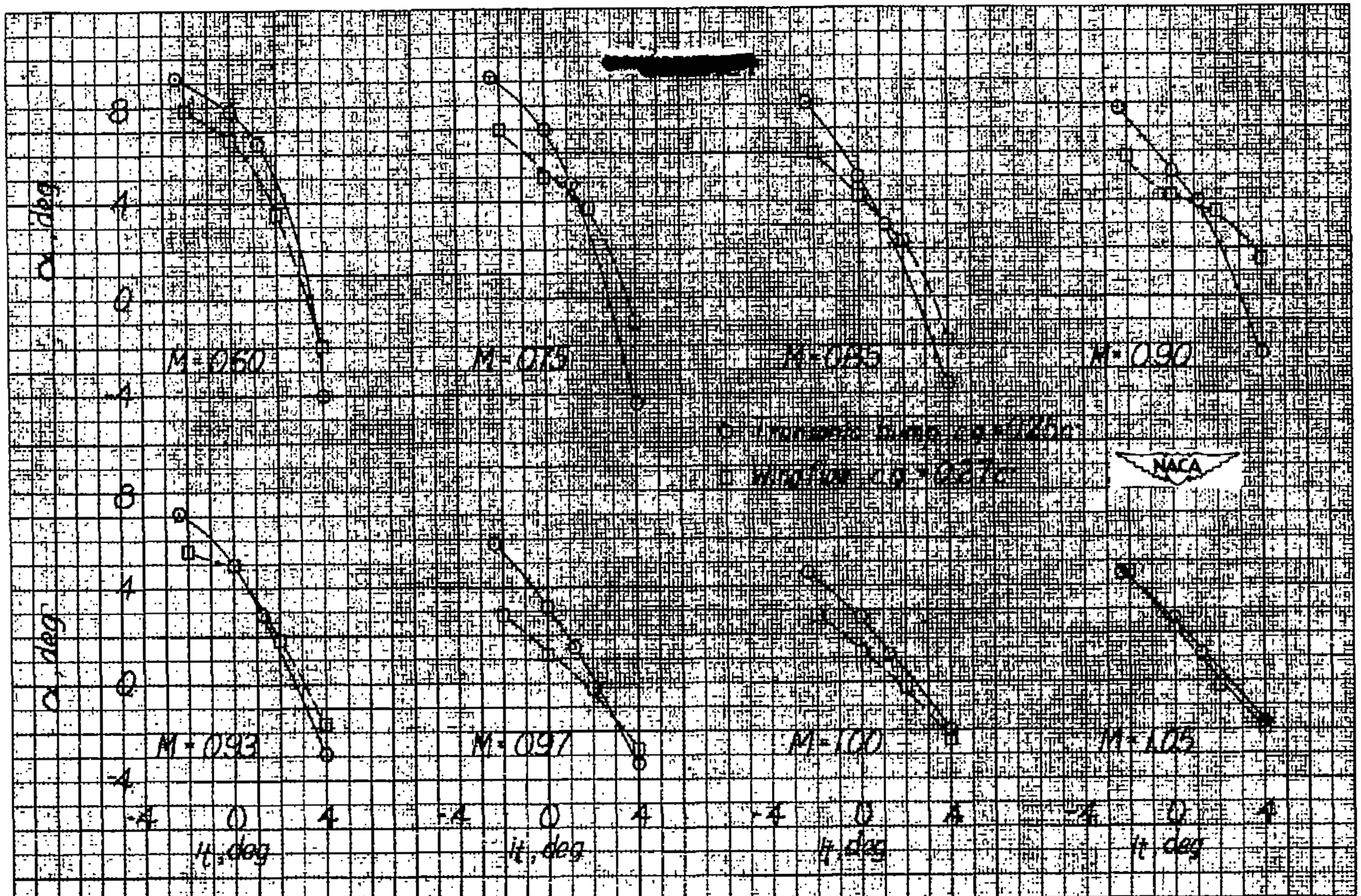

Figure 12.- Variation of angle of attack for trim with stabilizer incidence for various Mach numbers.

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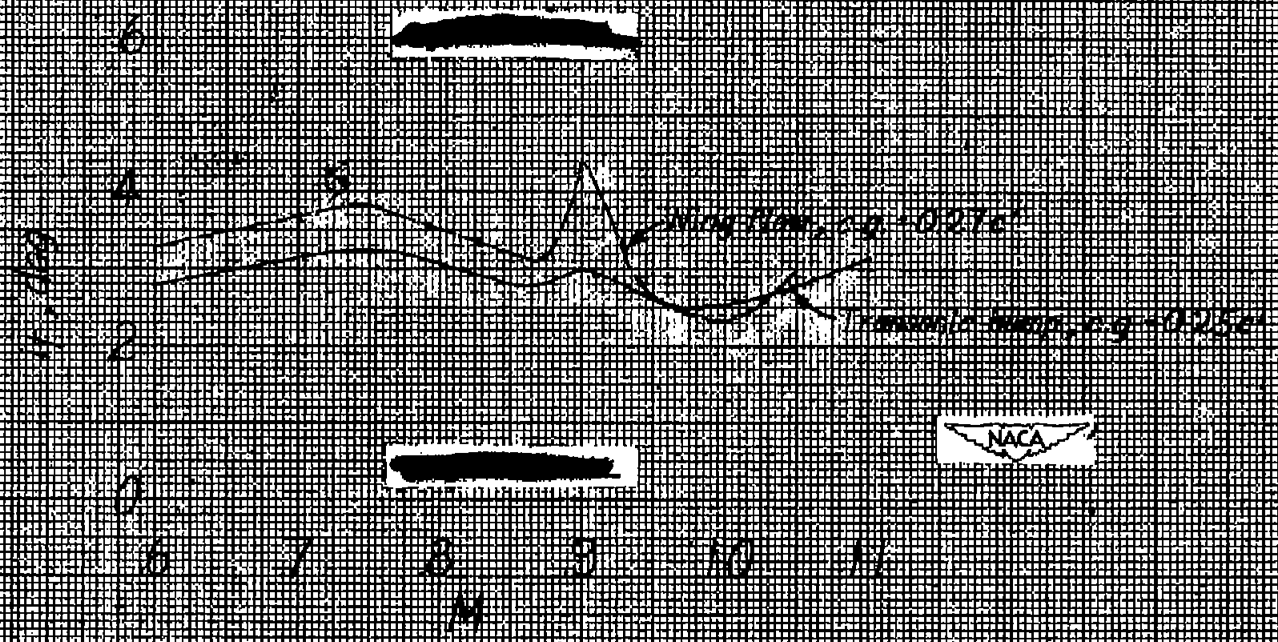

Figure 13.- Variation of stabilizer incidence required for trim with Mach number as determined by the transonic-bump method and the wing-flow method. W/S = 50 lb/sq ft; h = 30,000 ft.